Progress Report for RWO 44
DOI Amphibian Research and Monitoring Initiative:
Landscape Analysis of Okefenokee Swamp Vegetation Dynamics and Amphibian Species-Habitat Associations
Maine Cooperative Fish and Wildlife Research Unit
January 2004

Objectives for January – December 2003

1. Begin programming the vegetation succession and fire spread model using SELES.
2. Analysis of amphibian-vegetation associations.
3. PhD student prepares for comprehensive written and oral exam.
4. Prepare manuscript describing vegetation change in Okefenokee Swamp.

Progress

Objective 1 Developed a descriptive model of rules that will drive the processes of vegetation succession and fire within Okefenokee Swamp. The rules are now being coded into SELES programming language; see **Appendix A.**

Objective 2 Analyzed amphibian inventory and monitoring survey data that were collected by the USGS-BRD Florida Integrated Science Center (FISC); data were compared with the vegetation maps (see **Appendix B);** we will continue this analysis during early 2004.

Objective 3 Written exams completed; oral exam scheduled for 9 February 2004

Objective 4 Manuscript draft prepared for publication in *Wetlands*; in revision.

January – July 2004

Interval Objectives:

1. Complete programming the vegetation succession and fire spread model using SELES; analyze modeled output.
2. Develop time series model to forecast potential severity of wildfire.
3. Draft final synthesis.

Approach:

Objective 1

Historical fire, water level, and vegetation data have been organized for the purpose of developing rules for vegetation succession and fire spread. The rules are being compiled in a spatial model, which is being coded with the help of a professional computer programmer. The programmer is using a high-level modeling language called Spatially Explicit Landscape Event Simulator (SELES). The model will be calibrated and validated by comparing model output to historical fire, water level, and vegetation data during early 2004.

Objective 2

National fire management policies aimed at predicting fire behavior have been largely unsuccessful and are inappropriate for ecosystems like ONWR. If predictive management scenarios are needed, they should be performed at the appropriate (larger) scales. At larger scales there are observable patterns in natural systems like ONWR, which suggest some constancy in parameters and ranking of processes.

We have determined the areas burned by wildfire between 1941-2001. We will use time series models that consider previously burned areas and the Southern Oscillation Index (SOI) of the El Nino-Southern Oscillation (ENSO) conditions to predict potentially severe wildfire years. Such models may be far more effective than small-scale fire behavior models for developing proactive management policies. This work will be done during early 2004.

Objective 3

Results and analysis of satellite image classification, change detection, vegetation succession/fire model, and time series analysis will be written for a Ph.D. Dissertation. Each chapter will be submitted to appropriate peer-reviewed journals and will be submitted as sections of a final report for the project.

APPENDIX A

Modeling the Effects of an Altered Fire Regime on Vegetation Succession and Amphibian Habitat Associations within the Okefenokee Swamp

Hamilton (1982) and Loftin (1998) have suggested that vegetation communities within the Okefenokee National Wildlife Refuge (ONWR) are progressing towards a fire intolerant, hardwood system due to over 100 years of fire suppression and historical logging practices. With changes in composition and distribution of vegetation assemblages, habitat quality for ONWR wetland-dependent wildlife, such as amphibians, is potentially altered. The theory that landscape-scale vegetation change is resulting from historic wetland fire management and logging can only be tested through computer simulation, because the temporal and spatial scales of the variables are too great to be measured in a typical controlled experiment. Furthermore, the nonlinear nature of the variables and the interactions among processes make such a dynamic system impossible to replicate without abstraction.

Historical ecological research (e.g., Hamilton 1982, Loftin 1998) indicates that landscape vegetation patterns within ONWR develop primarily through the processes of fire, peat accumulation, and vegetation succession. These processes are in turn affected by water level and hydroperiod (duration of inundation), which are driven primarily by climatic and topographic features. Other factors such as human activities, hurricanes, nutrient cycling, plant production, and peat accumulation also affect vegetation succession but will not be considered in this model.

Landscape patterning processes in the ONWR operate at the mesoscale (i.e., areas of tens to hundreds of meters and time frequencies of decades to centuries). This model will project landscape change by decades over centuries, and will be based on a 14-class vegetation map developed using SPOT satellite data (10 m spatial resolution) collected during 2001. The model will look at the relationship between vegetation structure (e.g., composition, patch size, patch connectivity, edge amount, and other measures of diversity) and environmental processes (i.e., hydrology and succession), and disturbances (i.e., fire and drought). Our primary objective is to gain understanding of the two-way interaction between disturbance and vegetation structure (i.e., the effects of fire on landscape pattern and how landscape pattern affects the spread of fire), and how selected amphibian life-history types (represented by selected species) are potentially affected by the resulting change in ONWR vegetation distributions.

FIRE

Fire behavior has three distinct components: ignition, spread, energy release. Only ignition and spread will be considered here (figure 1). Lightning is the primary source of fires within ONWR and is most common during the summer. Because the likelihood of fire ignition in ONWR varies seasonally, we have divided the year into three categories. May-September indicates high likelihood of fire; October-November indicates moderate likelihood; and, December-April has a low likelihood due to the lack of thunderstorm-generated lightning.

Fire propagation is influenced by fuel density, moisture content, atmospheric humidity, wind speed and direction, and soil moisture/water level (Rothermel 1983). Our model considers fuel moisture content, humidity, and soil moisture to be a function of water level and hydroperiod. Whether or not a plant within a vegetation class ignites and spreads is a function of many factors including species, age, physiological status at the time the fire occurs, plant competition, and hydrology. This model only considers tolerance and susceptibility of dominant species to fire, water level, and hydroperiod. We are also analyzing historical wind data to determine the prevailing wind for each season to affect fire behavior.

The most important factor in fire behavior is the amount of fuel and its moisture content (Rothermel 1983). These variables vary daily, seasonally, and between wet and dry years. In our model the amount of fuel will be a function of the time since last fire and the vegetation class (e.g., shrub communities have more fuel than herbaceous prairies). Plant species that senesce during winter (e.g., Cypress) cause an increase in the amount of dead fuel. In addition, rare winter frosts can also increase the amount of dead fuel (Cypert 1973).

Lower precipitation during the dry season (December-May) and increasing evapotranspiration due to leaf growth (April-May) result in low water levels and litter moisture content in early spring. Therefore, optimal conditions for wildfire spread occur at the end of the dry season (May-June), when water levels are at their lowest, dead fuels are abundant and dry, and the first summer storms provide lightning as a source of ignition (Silveira 1996). Fires at this time of the year propagate easily and may be moderate to severe.

Lightning is common during the wet season (June-November), and fires caused by lightning are often ignited. However, water levels are higher during this time, making fuels moist and less likely to burn extensively. Consequently, fires burn only a limited area around the strike location and are of low intensity.

During extended periods of drought, the peat surface itself may become dry enough to burn. In drought, the absence of standing water permits plants adapted to shorter hydroperiods to grow in the aquatic prairies (Silveira 1996). Over time the dry fuel conditions coupled with increased fuel density create the potential for intense fires that spread quickly over large areas.

Summary- Optimal conditions for wildfire ignition and spread occur at the end of the dry season (May-June), when water levels are at their lowest, dead fuels are abundant and dry, and the first summer storms provide lightning as a source of ignition. July-November (wet season) indicates moderate likelihood of fire (low intensity). December-April indicates a low likelihood of fire due to the lack of thunderstorm-generated lightning. The prevailing winds determine the direction a fire will spread. Drought can cause large, intense fires. The amount of fuel will be a function of the time since last fire and the vegetation class (e.g., shrub communities have more fuel than herbaceous prairies). In addition, each vegetation class has fire tolerances and susceptibilities. For example, Loblolly Bay will not burn as readily as Cypress, but Cypress will tolerate fire much better. In addition, the roots of Loblolly Bay are much shallower than Cypress, so if fire gets into the peat Loblolly Bay will usually not survive. Herbaceous prairie will burn quickly and easily when dry, but can recover in weeks during the growing season if the water levels are high enough.

SUCCESSION

The environmental conditions driving vegetation succession in ONWR are water level and hydroperiod (figure 2). Although we are focusing on the effects of fire on landscape pattern and how landscape pattern affects the spread of fire, hydrological conditions also influence ONWR vegetation dynamics and are the basis for the rules determining fire spread. In the absence of fire, lower water levels and shorter hydroperiods facilitate succession from herbaceous to woody vegetation. Higher water levels and longer hydroperiods reset the progression; however, this "backwards" progression caused by extended hydroperiod will not be considered in this model.

Vegetation itself influences water levels and hydroperiods by building peat. Peat accumulation moves succession forward by raising the elevation, reducing water levels and hydroperiod. However, peat formation depends on saturation to slow decomposition, so fluctuations in water level and hydroperiod must be synchronized for the peat surface elevation to increase. In addition, as early successional species become more abundant they are eventually replaced by shade-tolerant species. Thus, competitive interactions and peat formation will be abstractly considered in this model.

Fire potentially reverses succession in ONWR. Fire frequency and intensity determine the sequence of vegetation change in response to burning. In turn, water level and hydroperiod influence this response, as species' tolerances to flooding vary.

Herbaceous vegetation re-sprouts quickly after a burn of moderate intensity, but small woody seedlings with little energy stored in their root systems may not survive. Thus, succession of woody species may be set back with these fires. Without fire, peat will gradually accumulate and create conditions more favorable for flood-intolerant woody vegetation. Fires occurring later in the season when vegetation contains more moisture or when water levels are maintained by frequent precipitation are less likely to be severe or spread, unless drought conditions prevail. These fires are less likely to result in long-term vegetation change unless they occur with drought.

Many of the wetland vegetation species in ONWR tolerate frequent, low-intensity fires. Most species re-sprout quickly following low intensity burns, unless the fire is followed by a long period of deep flooding. Low-intensity fires maintain, rather than change, wetland vegetation patterns at the landscape level (Silveira 1996).

Extremely intense fires can cause long-term changes in the vegetation pattern. The high heat penetrates into the peat, killing the roots of some plants. Although rare, fires can also burn into the peat and lower the surface elevation. The lower elevation increases hydroperiod following drought, leading to long-term shifts in composition and distribution of swamp vegetation assemblages. Likewise, frequent fires may cause changes of longer duration.

Upland islands within ONWR follow a different successional pattern (figure 3). Being higher in elevation and considerably drier, upland islands are likely areas for a fire to start and spread.

Summary- In the absence of fire, lower water levels and shorter hydroperiods facilitate succession from herbaceous to woody vegetation. Fire potentially reverses succession in ONWR. Fire frequency and intensity determine the sequence of vegetation change in response to burning. In turn, water level and hydroperiod influence this response, as species' tolerances to flooding vary. Fire frequency determines whether the Shrub class succeeds to the Cypress/Gum/Shrub class or the Gum/Bay/Shrub class (figure 2). In turn, water level and hydroperiod determine whether the Gum/Bay/Shrub class succeeds to the Loblolly Bay class or the Gum/Maple/Bay class (figure 2).

AMPHIBIANS

Recent studies have indicated that amphibian populations are declining worldwide at an alarming rate (Alford and Richards 1999). Causes of these declines vary regionally and include ultraviolet radiation, predation, habitat loss, environmental toxins, disease, changes in climate, and interactions among these factors (Alford and Richards 1999). There are approximately 38 species of amphibians found within ONWR and many travel long distances among various aquatic and terrestrial habitats and use different habitats at different stages of their life cycle (Alford and Richards 1999). If the altered fire regime within ONWR has drastically altered vegetation diversity and distributions, amphibian populations may be adversely effected.

I will use multiple regression analysis to examine the relationships between landscape scale habitat variables (e.g., measures of composition, edge, patch, and diversity) and anuran abundance and richness. Anurans will be grouped into guilds based on preferred habitat (derived from the literature) during the breeding and non-breeding seasons. Amphibians with broad environmental tolerances should be less affected by changes in vegetation than those that have limited mobility or require specific land types for breeding. A moderate number of models will be considered based on alternative hypotheses. I will use Akaike's Information Criterion to select the most parsimonious models.

DATA

- 14-class vegetation map developed from 2001 SPOT data (10 m resolution).
- Vector polygons showing fire location and area burned (1941-2001).
- Water level from two point locations within the swamp (1941-2001).
- Water level output (in two week intervals from 1941-1990). Output is from Hyrdrology model developed in ArcInfo macro language (AML). Model uses historical precipitation data, the above water level data, and evapotranspiration calculations as input. The output is in grid format (500 m resolution) and shows spatial differences in water level throughout the swamp.
- Daily wind speed and direction from 1979-2002.
- Vegetation raster maps (10 m resolution) from 1900, 1952, and 1990.
- DEM and peat depth map (500 m resolution)
- Hydroperiod coverages estimated from hydrology model output.
- Conversion of all data layers to 10 m resolution.
- Calculation of mean number of fires per time period (fire frequency), the mean time period between fires (fire return interval). These do not indicate how often a point on the ground might be expected to burn, so fire rotation time will also be calculated (total area divided by the mean area burned annually)

LITERATURE CITED

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Loftin, C. S. 1998. Assessing patterns and processes of landscape change in Okefenokee Swamp, Georgia. Ph.D. Dissertation, University of Florida, Gainsville, Florida, 864 pp.

Rothermel, R. C. 1983. How to predict the spread and intensity of forest and range fires. USDA Forest Service General Technical Report INT 143. USDA Forest Service Intermountain Rangeland Experiment Station, Ogden, UT.

Silveira, J. E. 1996. Landscape dynamics in the Everglades: Vegetation pattern and disturbance in water conservation area 1. Ph.D. Dissertation, University of Florida, Gainsville, Florida, 177 pp.

Figure 1. Conceptual model of processes contributing to fire ignition and spread within Okefenokee National Wildlife Refuge.

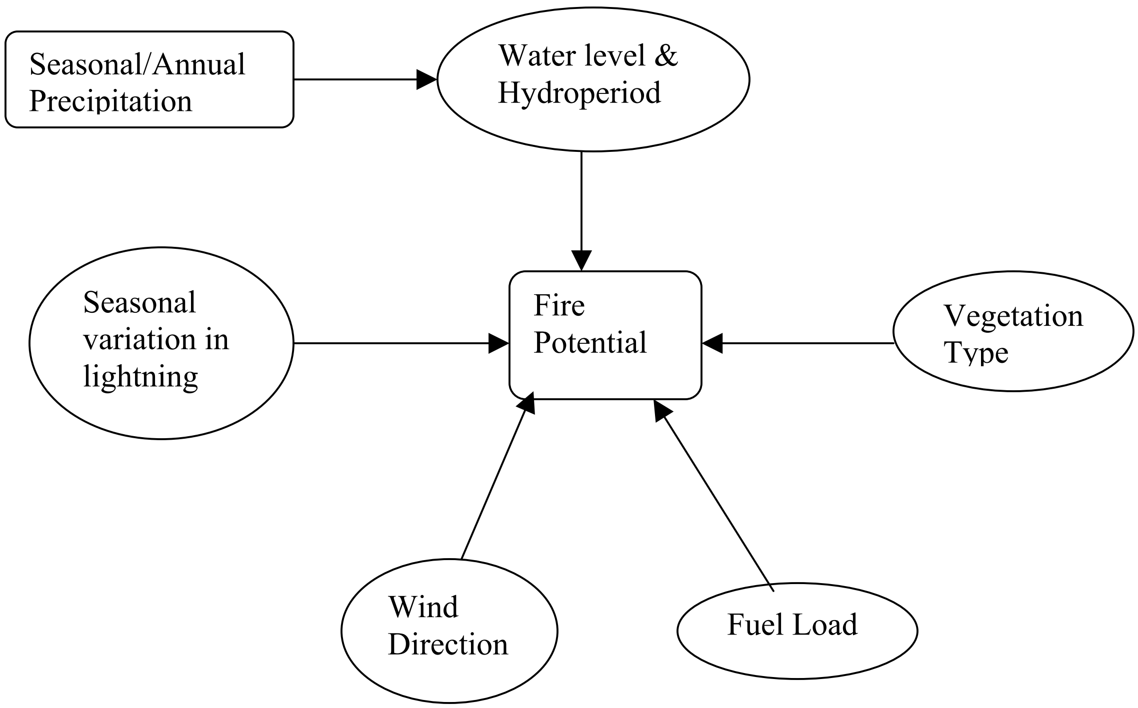


Figure 2. Conceptual model of vegetation succession within Okefenokee National Wildlife Refuge. Succession proceeds based on: 1 = Low water, short hydroperiod; 2 = Frequent, low intensity fires; 3 = Less frequent, low intensity fires. High water, long hydroperiod = 4. Fire frequency and intensity determines how far back succession is pushed.

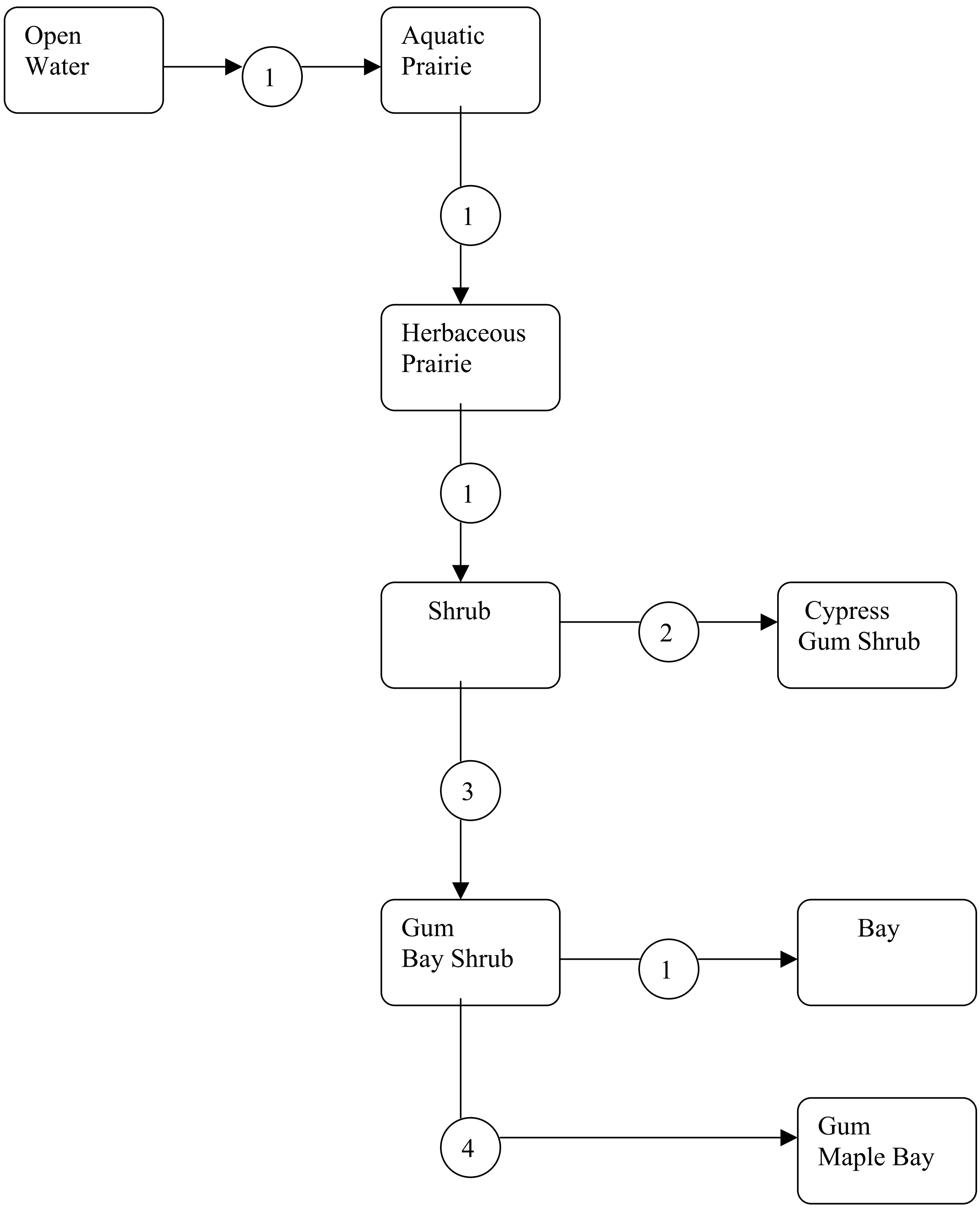
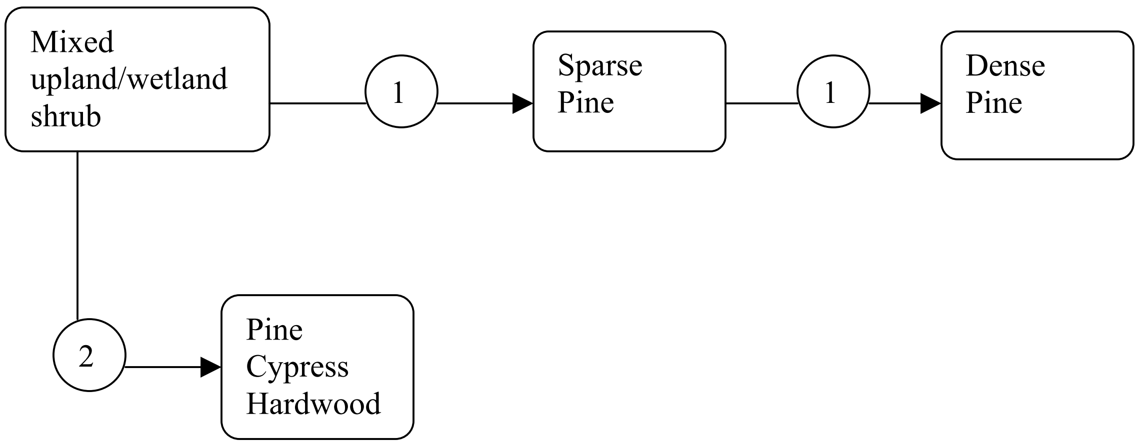


Figure 3. Conceptual model of vegetation succession on upland islands within Okefenokee National Wildlife Refuge. Succession proceeds based on: 1 = in the absence of fire and 2 = high precipitation or standing water. Fire frequency and intensity determines how far back succession is pushed.



APPENDIX B

Comparison of Okefenokee Swamp Amphibian Species Distributions and Wetland Vegetation Composition

PURPOSE AND METHODS

The Okefenokee National Wildlife Refuge (ONWR) amphibian inventory and monitoring surveys were conducted during 2000-2001 by the USGS-BRD Florida Integrated Science Center (FISC). Location, survey date, species encountered, and general habitat descriptions were recorded at sites along boat-accessible waterways and roadside wetlands in the ONWR (Figure 1). Concurrently, we developed a vegetation map of the ONWR by classifying 2001 SPOT multispectral and panchromatic satellite imagery and ground-truthing the map using georeferenced, digital aerial photography (Figure 1). This map will also provide baseline vegetation distributions for the spatial fire model we are developing. The purpose of this study was to use the FISC inventory data along with landscape variables (e.g., metrics of composition, patch, and degree of isolation) to develop models to examine how (or if) such variables were associated with amphibian species richness within ONWR. We were also interested in developing models to predict presence/absence of anuran species in response to landscape variables.

Wetland vegetation composition in the vicinity of the surveyed points was compared to that within the entire refuge. This was intended to determine if the environments around the surveyed sites were unique. Preceding this comparison, we pruned the amphibian survey dataset to maximize data independence and minimize survey error attributable to survey methodology. Of the 379 surveyed locations, 263 were repeatedly sampled and therefore did not represent independent survey results or equal survey effort among sampled points. To reduce bias that could be attributed to uneven survey effort, we removed the redundant locations, retaining data from only the initial visit. Amphibians were sampled in all months of the year. To minimize detection error, however, we deleted January and February data because amphibians are less detectable in colder weather. This resulted in 116 locations that could be considered independent.

We selected 50 m as the radius around each sampling point to represent the area used by the surveyed species. Because occurrence of surface water within most areas of ONWR is not limited, many amphibians may not have large home ranges (Lora Smith, pers. comm.). Therefore, we believed the polygon encompassing this area (~7854 m^2) appropriately described the variety of vegetation types used by the surveyed species. If two or more polygons intersected (i.e., points were within 100 m of each other resulting in overlapping radii), we removed one or more of the points from the dataset. This reduced error attributable to spatial autocorrelation. The final, pruned dataset contained amphibian survey results (i.e., species composition and species richness) for 97 locations that could be considered independent (Figure 1).

From the 14-class vegetation map, we calculated the proportion of each vegetation type within the entire ONWR (Table 1). We also calculated the overall proportion of each vegetation type within all 97 polygons (Table 1). We assumed that the survey locations were selected randomly to represent amphibian species composition in ONWR. It was necessary to determine if the relative proportions of each vegetation type were similar in the sampled area and the surrounding swamp, so that we could develop statistical models using data collected from the sampled areas that described relationships among species distributions and wetland vegetation associations, and then extrapolate those relationships beyond the sampled area to the entire swamp. If the sampled area was not representative of the surrounding swamp, then the amphibian habitat associations could be described only for the area sampled. Thus, we used Chi-square Goodness of Fit to test the hypothesis that the area sampled for amphibians was representative of the entire swamp (i.e., the sampled area has the same relative proportions of each vegetation type). Following this comparison we used classification and regression tree (CART) analysis to explore whether or not amphibian species richness was associated with vegetation composition. We also used CART to predict presence/absence of three of the most frequently found anuran species (cricket frog, *Acris gryllus*; southern toad, *Bufo terrestrris;* pine woods tree frog, *Hyla femoralis*). These species represent amphibians that occupy slightly different environments (cricket frog: open, longer hydroperiod wetlands with emergent vegetation; southern toad: wet, sandy areas with shallow water available for breeding; pine woods tree frog: pine flatwoods and forested wetlands). We ran three regression trees for each of the four separate response variables (species richness and occurrence of the selected 3 species) using 1) all 97 survey locations; 2) survey locations from only uplands (including higher elevation areas of the perimeter and larger islands within the swamp; $n = 33$); and, 3) survey locations from only the interior wetland region of the swamp ($n = 64$).

RESULTS

The Chi-square statistic was considerably higher than the critical value, indicating that the area sampled was not representative of the entire swamp (Table 1). This suggests that it would not be appropriate to extrapolate species-habitat relationships beyond the sampled areas in application of the spatial model describing vegetation response to fire. Nevertheless, we further explored relationships among encountered amphibians and vegetation types within the surveyed areas.

The overall result of the CART analysis is that there were no good models that could be generated with the available species inventory and habitat dataset (Table 2). The results presented in Table 2 are based on the "best" model that could be generated from the pruned dataset. The information presented in Table 2 includes the misclassification rate, which indicates the number of cases the model misclassified out of the total number of sampled sites. For example, for the presence/absence data for each species, if a site was occupied by the species and the model said it was not occupied, there has been a misclassification. Predictor variables that were in each model are also presented in Table 2. These are the vegetation types selected by the models for that species. Finally, Table 2 indicates whether the model could be validated based on data re-sampling using a cross validation procedure and indicates if a model could be generated. If a model could be supported based on the data, we indicate with a number of nodes how large the "best" model was. However, model validation does not indicate biological relevance. For example, the vegetation class “Bare Ground” was chosen as a predictor for two of the twelve models. It is most likely that this was not because that land cover type is biologically relevant, but because survey locations were often close to roads fringed by a sandy or sparsely vegetated shoulder.

The results of species richness associations with swamp vegetation type also indicate that there is no good model that can be generated from the pruned dataset. The total r^2 for the total dataset (pruned) is only 16%, while the associations on the island and wetland interior sites have an r^2 of only 25%. This indicates that although there are trends in amphibian occurrence and vegetation type, they are not well-defined, and thus the vegetation type-based models explain little of the variation in species occurrence and richness across these sites.

RECOMMENDATIONS

There are several factors that might be incorporated in designing future amphibian surveying efforts to increase the dataset spatial resolution so that associations with Okefenokee Swamp wetland vegetation type might be further examined. These improvements fall into two types: 1) distribution and independence of survey sites and 2) increased resolution of vegetation data.

Distribution and Independence of Survey Data. If extrapolations to a greater extent are to be made from the sampled sites, relationships that are described between the response variable (such as species occurrence) and independent variables (such as vegetation types) should include samples drawn from the full spectrum of possible conditions. The amphibian survey plan necessitated readily accessible sampling routes, eliminating much of the refuge that is difficult to reach. Unfortunately, this also affected how representative the survey data would be of the un-sampled areas. Easily accessible areas within the refuge interior are along waterways (e.g., canals, canoe trails), in the perimeter uplands (e.g., isolated ponds), or on islands (e.g., wetland along the island edge or isolated ponds) that can be reached by boat and then approached on foot. Sample sites in these areas over-represented certain vegetation types in the dataset. Classes containing pine (e.g., mixed wet pine, sparse pine, dense pine, and pine-cypress-hardwoods) are most frequently found on the swamp islands and upland perimeter areas and cover approximately 10% of the refuge; 32% of the sampled sites occurred in these pine-dominated areas which surrounded isolated, upland ponds. The pine vegetation types were detected on the imagery, but the ponds were obscured by this vegetation, or were so small that they were not detected in the image data. The bare ground type is limited to approximately 0.3% of the refuge along road edges and scattered clearings on the interior islands. This type was also over-represented in the sample sites (5.1%), most likely because it occurred along access routes to the sampled sites or open areas around the sampled ponds. In contrast, the surveyed sites under-represented the shrub, loblolly bay, and cypress-gum-shrub types (27% of the sampled sites), which are fairly widespread in the swamp (covering approximately 63% of the refuge), but they are generally away from the canoe trails and canals and therefore are difficult to access. Other vegetation types (e.g., sedges-ferns-water lilies, gum-maple-bay, and gum-bay-cypress-shrub) were included in the surveyed sites in roughly the same proportions (24%) as they occur in the refuge as a whole (21%). If the intention is to use the surveys as an indication of amphibian occurrence or species richness throughout the refuge, then future survey routes and sites should be selected to proportionally represent the vegetation communities occurring in the swamp. This could be accomplished using a random sample design spatially stratified by vegetation types and sample numbers weighted by area of vegetation type.

Repeatedly surveying sites for amphibian composition improves the resolution of data at a location, but spatial autocorrelation among those data values prohibits using them as independent observations. Thus, in order to relate the amphibian point data to the vegetation types at the sampled points, repeatedly sampled sites had to be pruned to represent data collected at independent locations (i.e., the total data set of 379 surveyed locations was reduced to 97 points). Additionally, locations closer than the minimum buffer (i.e., 50m) were eliminated to reduce potential overlap between adjacent sites. A more populated dataset with a greater distance between sites (e.g., distance greater than 50m between repeated samples) may have revealed stronger relationships among the species composition and vegetation types at the sampled points.

Increased Resolution of Vegetation Data. The failure of the CART analysis to find definitive amphibian habitat associations may be due to several factors: an inappropriate scale of observation (i.e., amphibian species that may meet all of their habitat needs in a small area and vegetation types represented by data that are more course than the response scale of the amphibian species); a map composition comprised of vegetation types to which the swamp amphibians do not respond; small numbers of amphibian observations; or, habitat associations determined based on overstory vegetation reflectance data that may mask the conditions in the subcanopy to which the amphibians are responding (e.g., small isolated ponds that are not distinguished in the 10m pixel satellite data from the surrounding pine forest). The Okefenokee Swamp landscape is highly fragmented and heterogeneous. The SPOT satellite imagery that provided the digital data for the vegetation map was collected at 10m (panchromatic) and 20m (multi-spectral) resolutions and merged to create a final image with 10 m pixel resolution. The map was fairly accurate; the 14-class map was created by combining selected classes in an 18-class map with an estimated overall accuracy of 86% within the refuge boundary. However, the 100m2 patches (10mx10m pixels) of spectral data summarizing the vegetation occurring in a particular area may be more course than the actual scale at which the amphibian species are selecting sites to inhabit. In addition, microhabitat variations that are important to amphibians but obscured by the forest overstory could be undetected. Interspersion of vegetation types may be such that amphibians meet their habitat requirements within a relatively short travel distance, and except in occasional very dry periods, the abundance of water enables them to be relatively sedentary, possibly within the area represented by a few pixels of spectral data. In extensive areas of homogenous vegetation types, the amphibians may not be as selective in choosing specific locations within the types. However, in more highly fragmented areas of the swamp or in areas where vegetation diversity is greater over distances less than the 10m pixel mapping unit, the species-habitat affinity may be unrecognizable at the 10 m pixel scale.

It is also possible that the vegetation types that were spectrally distinguishable in the imagery are not types discriminated by the selected amphibian species. Although the CART analysis suggests that in some situations the selected species demonstrated vegetation type affinities described by models that made ecological sense, most models performed poorly (i.e., high misclassification rates, few model nodes). For example, in the analysis using only the islands/uplands points (n=33), the model predicting presence/absence of pine woods tree frogs correctly classified 75% of the sites and included sparse pine and bare ground as the predictor variables. These vegetation types occur around isolated ponds in the interior islands and upland perimeter that may have been undetected in the imagery due to their small size. The model for pine woods tree frog using data from only the swamp interior wetlands included four variables (loblolly bay, shrub, pine-cypress-hardwood, cypress-gum-shrub) and had a 70% correct classification rate. These vegetation types are quite different from those included in the upland model for this species, possibly due to the image resolution obscuring the vegetation fringing small, isolated wetlands. An additional source of error is also possible, however: the selected amphibian species were abundant and widespread, indicating that they are not associated exclusively with any single vegetation type. This attribute would increase their resilience to changes in the swamp wetland vegetation distributions, making them poor indicators of changing wetland quality. Therefore, improvements would be gained with an increased number of samples of species with more specific habitat requirements, discrimination of vegetation types based on these requirements, and spectral data with greater spatial resolution.

We are continuing to explore the dataset to describe habitat affinities of the selected amphibian species with other methods (since sample numbers were small and therefore may have affected the effectiveness of the CART analysis), as well as repeating the analysis to include other species most abundant in the dataset. We will summarize those analyses in a subsequent report.

Table 1. Chi-square Goodness of Fit used to determine if the sampled area had the same relative proportions of each vegetation type as exists across the entire Okefenokee National Wildlife Refuge.

Vegetation Type	Proportion in entire refuge	Proportion in sampled area	Observed Cell Count	Expected Cell Count	$(O-E)^2/E$
Loblolly Bay	9.2	4.8	363	698	160.78
Sedges, Ferns, Water Lily	7.3	7.9	600	554	3.82
Water Lily	4.8	9.4	713	364	334.62
Mixed Wet Pine	2.1	0.9	66	159	54.4
Cypress, Gum, Shrub	22.2	12.3	932	1685	336.5
Bare Ground	0.3	5.1	385	23	5697.56
Sparse Pine	3.1	15.3	1163	235	3664.61
Water	0.06	1.4	110	5	2205
Gum, Maple, Bay	4.1	4.8	363	311	8.69
Dense Pine	3.5	12.7	966	266	1842.1
Pine, Cypress, Hardwood	1.2	3.4	255	91	295.56
Shrub	31.6	9.6	726	2398	1165.8
Gum, Bay, Cypress, Shrub	9.7	10.8	816	736	8.7
Mixed Upland/Wetland Shrub	0.6	1.7	132	45	168.2
			Total= 7590		Sum= 15946.35

Critical value $X^2_{0.05,\ 13} = 22.36$

Table 2. Classification and regression tree results indicating validity of models predicting presence/absence of *Acris gryllus* (Agr), *Bufo terrestrris* (Bte), and *Hyla femoralis* (Hfe), and species richness associations.

All sites (*n* = *97*)	**Misclassification Rate**	**Variables in Model**	**Based on re-sampling is a model possible?**	**Comments**
Species richness	0.701 = 68 / 97	Dense Pine Cypress Gum Shrub	No (3 node model)	No model was validated, so the summary is based the best model created. We used a very small model (3 nodes).
Hfe	0.4124 = 40 / 97	Bare Ground Sparse Pine	No (3 node model)	No model was validated, so the summary is based the best model created. We used a very small model (3 nodes).
Bte	0.1856 = 18 / 97	Pine Cypress Hardwood Cypress Gum Shrub	No (3 node model)	No model was validated, so the summary is based the best model created. We used a very small model (3 nodes).
Agr	0.2165 = 21 / 97	Dense Pine Gum Bay Cypress Shrub	No (3 node model)	No model was validated, so the summary is based the best model created. We used a very small model (3 nodes).
Islands (*n* = 33)	**Misclassification Rate**	**Variables in Model**	**Based on re-sampling is a model possible?**	**Comments**
Species richness	0.5758 = 19 / 33	Dense Pine	Yes (3 node model)	Misclassified over half of the sites. Is made up of only one variable.
Hfe	0.2424 = 8 / 33	Bare Ground Sparse Pine	Yes (3 node model)	Misclassification rate is high, so the model does not perform well. It is probably an artifact of the limited sample size.
Bte	0.09091 = 3 / 33	Dense Pine	Yes (3 node model)	Predicts all absents (only 3 cases where the species was present on the islands). Thus, it is really not a biologically relevant model
Agr	0.2424 = 8 / 33	Dense Pine Sparse Pine	Yes (4 node model)	Misclassification rate is high, so the model does not perform well. It is probably an artifact of the limited

				sample size.
Wetland (*n* = 64)	**Misclassification Rate**	**Variables in Model**	**Based on re-sampling is a model possible?**	**Comments**
Species richness	0.5938 = 38 / 64	Cypress Gum Shrub	Yes (4 node model)	Misclassified over half of the sites. Is made up of only one variable; thus, is not a good model.
Hfe	0.2969 = 19 / 64	LoblollyBay Shrub Pine Cypress Hardwood Cypress Gum Shrub	Yes (5 node model)	Misclassification rate is high, so the model does not perform well. It is probably an artifact of the limited sample size.
Bte	0.2344 = 15 / 64	Water Lily Pine Cypress Hardwood	No (3 node model)	No model was validated, so the summary is based the best model created. We used a very small model (3 nodes).
Agr	0.125 = 8 / 64	Gum Bay Cypress Shrub	Yes (3 node model)	Predicts present in all sites; Agr is nearly everywhere on the land sites. Poor model.

Figure 1. 14-class vegetation map of Okefenokee National Wildlife Refuge showing amphibian survey locations.